TELEHEALTH IN THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

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INTRODUCTION

Remote monitoring of crew health and safety has always been a fundamental element of the National Aeronautics and Space Administration's (NASA's) operations. Over the ensuing decades of human space flight, NASA has captured the benefits of the technological revolution—from early telecommunications satellites to the innovations of today's "information age"—to evolve original telemedicine capabilities into its current telehealth program. The use of cutting-edge technology to fulfill the needs of traditional health care ensures the survival of a crew in hostile or remote environments—from the distant jungles of Earth to the far reaches of the solar system. Following a brief discussion of telehealth history and technology, this paper will examine NASA's health care criteria and the unique challenges to health care in NASA missions. Finally, the paper will conclude by exploring the success of telehealth in improving space flight missions and quality of life on Earth.

TELEHEALTH IN PERSPECTIVE

Telemedicine, the practice of health care despite the geographic separation of the patient and provider network, first became a reality centuries ago in France with Laënnec's development of the stethoscope. Although the distance separating the doctor and patient was only a few centimeters, the leap in the potential of telemedicine was enormous.

In the centuries that followed, health care providers engineered new tools with which to exchange information across great distances at speeds much faster than those afforded by "modern" transportation methods. As technology developments led to new health care applications and capabilities, telemedicine evolved into telehealth—multidisciplinary health care across geographic separation.

The invention of the telegraph and telephone gave physicians the ability to send information at speeds limited only by the conducting medium (in this case, copper wire). The first telephones, for instance, allowed physicians to send 2 bits of information per second across phone lines. More advanced phones allowed the transfer of 64 kilobits of information per second.

Computers and the space age have meant further advances to the dissemination of medical information and medical care across distances. The costs of maintaining computing infrastructure have steadily dropped, while computing power has risen (Moravec, 1988), making computers a relatively inexpensive and very powerful health care tool. In addition, telecommunication satellites can link health care providers and patients around the world, without regard to location.

Coupled with exponentially increasing data rates (today's telecommunications satellites, for instance, can carry more than two gigabits, or 2×10^9 bits, per second), current telecommunications and computing ability now provide physicians and their patients with real-time videoconferencing, video, high-resolution imaging, and virtual reality.

The theme of today's telehealth abilities can be summed up by one salient fact: physicians no longer relocate patients for diagnosis or consultation, they now move bits of information. Through the transfer of medical data (in the form of digitized x-rays, EKGs, and CAT scans, for instance), a patient in New York can quickly benefit from the expertise of a radiologist in Los Angeles, a cardiologist in Paris, and a neurologist in Moscow without ever leaving the state. As computing power and abilities continue to increase, NASA's telehealth abilities grow apace.

THE ROLE OF TELEHEALTH IN HUMAN SPACE FLIGHT

Telehealth capabilities are essential to the proper operation and maintenance of all three aspects of human space flight: the *human* crew, spacecraft *systems*, and the space flight *environment*. Ground controllers and space crews monitor environmental factors (radiation levels, air quality, etc.) and system functions via equipment that shares a technological foundation with telehealth. This paper, however, focuses on the role that telehealth plays in the care and treatment of the human factor—the crews of a space mission, or even the remote populations on Earth.

Telehealth plays a vital role in the health and safety of a space crews throughout a mission. Both pre-flight and during a mission, telehealth capabilities allow physicians to maintain the health and well-being of the crew. Physicians must monitor additional factors once the crew reaches orbit and their bodies adapt to microgravity: bone and muscle loss, changes to blood pressure and cardiac rhythm, fluid shifts, and a depressed immune response. Telehealth allows health care providers to monitor, treat, and in some cases prevent these adaptations while the astronauts are on-orbit. Furthermore, telehealth means the necessary communication and telemetry that meet the criteria for care in space: an ability to treat crew members and return them to duty; a minimization of the impact on the remaining crew; the ability to stabilize and/or evacuate a crewmember in low-Earth orbit; and the ability to provide for crew safety and remote consultation.

Following a mission, telehealth permits the mission medical staff to monitor and facilitate the crewmembers' readaptation process. Astronauts may suffer from neurosensory motor dysfunction, altered cardiac function, decreased immune function, localized bone loss, and decreased muscle strength and endurance. With NASA's monitoring capabilities, astronauts can receive the treatment and care necessary to regain pre-flight health.

NASA'S TELEHEALTH TESTBEDS IN SPACE AND ON EARTH

NASA's telehealth activities—both Earth- and space-based—have existed from the first days of the program. The continuing augmentation and refinement of the Agency's telehealth capability is dictated by increasing complexity and scope of space missions.

In early missions, NASA relied on telehealth capability for monitoring and simple automation. Until these missions, health care providers did not even agree that a human **could** survive in microgravity. Throughout the space program, including recent Space Shuttle activities, telehealth played a large role in furthering the understanding of the effects of microgravity on the human body. Today, as the Agency begins a new era of operations with the International Space Station, mission planners will rely on telehealth capabilities for monitoring, research, education, health care, psychological support, consultation, and diagnosis.

NASA's telehealth programs are not limited to space flight activities. Since the early 1970's, NASA has operated a wide-ranging network that links health providers and patients across the globe. Many of these endeavors are conducted in cooperation with the Department of Defense (e.g., the Telemedicine and Advanced Technology Research Center, or TATRIC, at Ft. Detrick), Commercial Space Centers (e.g. MITAC, the Medical Informatics and Technology Applications Consortium at Virginia Commonwealth University), universities, or private industry. The following enumeration represents just a few of NASA's many terrestrial telehealth programs:

- *Space Technology Applied to Rural Papago Advanced Health Care* (STARPAHC), 1972-1975: NASA conducted a unique testbed that linked the remote Papago Indian reservation to physicians in Sells, Arizona, via two-wave microwave and VHF;
- *Spacebridge to Armenia*, 1988: Under the auspices of the U.S./U.S.S.R Joint Working Group on Space Biology and Medicine, NASA connected physicians in the U.S. and Soviet Union with 209 victims of a devastating earthquake in Armenia. The Spacebridge, a space-based telecommunications network, remained in operation for three months. This same network assisted following a gas explosion in Ufa, Russia;
- *Spacebridge to Russia*, 1990's: Following the success of Spacebridge to Armenia, the U.S. and Russia teamed to demonstrate one of the first successful applications of the world-wide-web and multicasting in telehealth;
- *Everest Extreme Expeditions*, 1998-1999: Stationed at Everest Base Camp, Yale University physicians and scientists supported telemedicine activities, remotely monitored climbers on their way to the peak, evaluated new technology, and conducted research to further understand the cardiovascular response to extreme environments. Real-time grand rounds and emergency response between Base Camp and Yale were conducted via a 128-kbps link;
- *Operation Rainforest*, 1999: In collaboration with a mobile surgery clinic operated by the Cinterandes Foundation in Cuenca, Ecudaor, a team of NASA and other researchers provides surgical care to remote villages in Ecuador. This program brings interactive pre-operative and post-operative physician-physician and patient consultations to individuals located deep in the Andes and the rainforests;

- *Virtual Collaborative Clinic,* 2000+: The VCC is a joint effort between NASA-Glenn Research Center, Stanford University, Salinas Valley Memorial Hospital, Northern Navajo Medical Center, and NASA-Ames Research Center. The mission of the VCC is to provide interactive reconstructions of medical information to multiple clients for examination and analysis in a virtual environment. First evaluated in 1999, MITAC will begin full funding of VCC in June, 2000.

TELEHEALTH BEYOND NASA: TECHNOLOGY TRANSFER

One of NASA's major missions is the commercialization of Agency-sponsored research and technology. Not only does technology transfer boost the economic position of U.S. companies, but it also ensures the widest possible dissemination of new technologies. Telehealth in particular has played a large role in NASA's commercialization efforts, even beyond the terrestrial outreach mentioned above. The products described below are only a sample of the many NASA telehealth technologies currently in commercial development:

- *Pill-shaped biotransmitters*: Shaped like a small pill and therefore easily swallowed, these biotransmitters allow remotely-located physicians to monitor patient vital signs from within the patient's body. Developed by industrial partner Sensors 2000! (S2K), these sensors will be used in life science research on the International Space Station, and can be readily adapted to monitor the health of humans in space or on Earth;
- *Wireless Augmented Reality Prototype (WARP)*: WARP was conceived in 1996 as a means to provide astronauts with hands-free access to data and communications. WARP holds promise in both medicine and industry: teleconsultation, heads-up monitoring, inspection and inventory, remote monitoring, and hands-free maintenance diagrams. Commercial development of the WARP is currently in Phase II, with final delivery expected in 2002;
- *Electronic Nose (E-Nose)*: The E-Nose is a miniaturized monitoring instrument that detects and identifies a wide range of airborne molecules in a manner to similar to the human nose. NASA uses the E-nose for environmental monitoring on the Space Shuttle and, soon, the International Space Station. The commercial version of the E-nose has many applications in environmental monitoring, especially the detection of hazardous fumes in refineries, oil rigs, chemical plants, and security systems;
- *Telecollaboration On-Line Database (TOLD)*: This graphical user interface actually represents the original Spacebridge to Russia. TOLD allows a user to link to web-based medical records, complete with text, video, audio, and still images. NASA-MITAC is currently in negotiations to license the technology to several companies, including AT&T and CISCO.

TELEHEALTH TOMORROW: CONQUERING TIME AND DISTANCE

Astronauts journeying beyond low-Earth orbit (LEO) face two major obstacles:

time and distance. Today's activities on the Space Shuttle and International Space Station do not face this problem; real-time communications are standard procedure. In addition, the evacuation of a crewmember from LEO to Earth, while not an easy task, is nonetheless feasible. Long-duration exploration missions, however, face a much different scenario.

Time is the first barrier to real-time communications, telemetry, and consultations. A crew on an outbound journey will face one-way communications delays of minutes, sometimes hours. A message sent from a Mars-bound crew, for instance, can take up to 22 minutes to reach Earth; the reply takes an additional 22 minutes to receive. As we venture towards other, more distant planets, the communication lag becomes even more of a factor. Essentially, in the event of illness or injury, exploration crews must act and react independent of ground-based support.

This scenario for future long-distance missions also holds promise for NASA's growing telehealth abilities. The integration of nanotechnology and informatics approaches will allow mission crews to deal with medical events on their own. Autonomous on-board systems will provide astronauts with the necessary expertise and equipment for day-to-day health care. Store-and-forward technology will provide communications to and from Earth.

Distance will also pose a challenge as exploration proceeds outwards through the solar system. Long-duration exploratory crews will not have the option of a return to Earth in the event of illness or injury. Again, telehealth capabilities will yield a solution this problem. Because telehealth requires the movement of information bits, and not the patient, a physician on Earth can provide a space-faring user or patient with expertise in monitoring, imaging, dermatology, psychology, education, pharmacology, epidemiology, or even surgery.

THE FUTURE OF NASA TELEHEALTH

" When the pace of events and their variety make it more difficult to predict what will happen next week or next month, it is even more important to be oriented toward the long term…"

President Bill Clinton, 1998

Telehealth capabilities have already provided NASA physicians with a window into the physiology of the human body in microgravity. The concomitant increase in computing power and decrease in costs permit a relatively easy, inexpensive link between physicians and researchers worldwide and provide health care for individuals located in remote regions across the planet. As NASA continues its telehealth research, these new developments will be incorporated into both the space program and the health care industry.

Today's nanotechnology and informatics research will push telehealth capabilities even further. Current projects under development for NASA's Office of Life and Microgravity Sciences and Applications (OLMSA) include multipurpose tactile interface, intelligent databases, self-assembling nano-structures, biologically-inspired robots, and cybersurgery. In the coming years, these individual pieces will combine to create "smart", interconnected, autonomous, self-replicating, self-repairing telehealth systems—an essential component of long-duration exploration.

Telehealth will become an integral part of future space exploration as NASA continues to learn from its terrestrial- and space-based telehealth activities. Future telehealth activities that combine nanotechnology and medical informatics into complex, self-sustaining telehealth systems will enable health care for long-duration exploratory missions. As NASA's telehealth capabilities continue to grow, the Agency's ability to care for remotely-located patients—whether on Mount Everest in Nepal or Olympus Mons on Mars—will improve the quality of health care for all patients, on Earth and in space alike.

SELECTED REFERENCES

1988 Moravec, Hans. *Mind Children: The Future of Robot and Human Intelligence*. Cambridge: Harvard University Press.

1998 Doarn, CR, Nicogossian, AE, Merrell, RC. "Applications of Telemedicine in the United States Space Program." *Telemedicine Journal* 4(1), pp. 19-30

1999 *MITAC Annual Report*. Virginia Commonwealth University, Richmond, Va.

1999 Zajtchuk, Russ, and Gilbert, Gary. "Telemedicine: A New Dimension in the Practice of Medicine." *Disease-a-Month* 45(6), pp. 199-265.

NASA Telemedicine
ww.hq.nasa.gov/office/olmsa/aeromed/telemed/

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